Quantum states transfer by the analogous Bell states

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Transmitting quantum states by channels of analogous Bell states is studied in this paper. We analyse the transmitting process, constructed the probabilitic unitary operator, and gain the largest successful transfer quantum state probability.

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I. INTRODUCTION

It is well known that there are two ways to transfer quantum information: one can first use the channel to share entanglement with separated Alice and Bob and then use this entanglement for teleportation [1], or directly transmit a state through a quantum data bus. In the quantum information theory [2], transfer of information in the form of a prepared superposition quantum state is essential. And the important task in quantum-information processing is the transfer of quantum states from one location A to another location B[3]. One can transfer a quantum state either by the method of teleportation [1] or through quantum networking. The typical examples of quantum state transfer is the quantum storage based on various physical systems [4,5], such as the quasispin wave excitations [6]. Recently, schemes have been proposed that employ more than two qubits to perform various quantum information tasks [7,8,9]. There is also an interest in performing quantum teleportation of state of more than one qubit. Lee[10] has presented a setup for teleportation of an entangled state of two photons, such scheme as some other schemes [11], uses photons because they propagate fast and can carry quantum information over long distances. A state transfer between two identical distant systems is a process in which at time t=T the second system obtains the same quantum state that the first one had at time t=0[12]. In Ref.[13], it referces to the transfer quantum states by Bell states. We know that if the entanglement pairs are Bell states, the probability of transmitting quantum states is 100%. Generally, the Bell states are prepared via evolvement of H till $t = t_0$ which is the time that the states are prepared as Bell states. For example

$$|\phi\rangle = \sin t\,|00\rangle + \cos t\,|11\rangle$$

when $t = \frac{\pi}{4}$,

$$|\phi\rangle = \frac{1}{\sqrt{2}}\,|00\rangle + \frac{1}{\sqrt{2}}\,|11\rangle\,.$$

But for the difficulty of exactly controling the process, it is nearly no possibility to prepare the perfect Bell states. It is easy to produce some departures from Bell states. It is to say

$$|\phi\rangle = \sin(\frac{\pi}{4} + \triangle)\,|00\rangle + \cos(\frac{\pi}{4} + \triangle)\,|11\rangle\,.$$

In this paper, we name these states as the analogous Bell states. This condition will lead to be difficult to transmit quantum states of the system. Therefor, we try to deal with these troubles and specially we use one qubit of entanglement state in each entanglement pair as the channels to transmission.

In the Sec.II and Sec.III, we accomplish the probability of transmission quantum states by these analogous Bell states and some effective unitary operators. And we exhibit the relation between the probability and the departures with Fig.1 and Fig.2.

II. TRANSMITTING BIPARTITE QUANTUM STATES BY TWO ANALOGOUS BELL STATES

Here we suppose that Alice and Bob share two pairs entanglement particles. We suppose the entanglement states are:

$$\begin{aligned} |\phi\rangle_A &= a_A\,|00\rangle_A + b_A\,|11\rangle_A \quad |a_A|^2 + |b_A|^2 = 1 \quad (1)\\ a_A &= \sin(\frac{\pi}{4} + \triangle_A) \quad b_A = \cos(\frac{\pi}{4} + \triangle_A)\\ |\phi\rangle_B &= a_B\,|01\rangle_B + b_B\,|10\rangle_B \quad |a_B|^2 + |b_B|^2 = 1 \quad (2)\\ a_B &= \sin(\frac{\pi}{4} + \triangle_B) \quad b_B = \cos(\frac{\pi}{4} + \triangle_B). \end{aligned}$$

We show how to transmit an arbitrary bipartite state by two analogous Bell states

$$|\phi\rangle_{12} = c_1\,|00\rangle_{12} + c_2\,|01\rangle_{12} + c_3\,|10\rangle_{12} + c_4\,|11\rangle_{12} \quad (3)$$

The whole state is

$$\begin{aligned} |\Phi\rangle \;=\; & a_A a_B c_1\,|00\rangle_{12}\,|00\rangle_A\,|01\rangle_B + a_A b_B c_2\,|01\rangle_{12}\,|00\rangle_A\,|10\rangle_B \\ & + b_A a_B c_3\,|10\rangle_{12}\,|11\rangle_A\,|01\rangle_B + b_A b_B c_4\,|11\rangle_{12}\,|11\rangle_A\,|10\rangle_B\,. \end{aligned} \quad (4)$$

Then by carrying out Bell-operation on the first parti-

cle, we get

$$
\begin{aligned}
|\Phi\rangle = & \frac{1}{\sqrt{2}}(a_A a_B c_1 |00\rangle_{12} |00\rangle_A |01\rangle_B + \\
& a_A a_B c_1 |10\rangle_{12} |00\rangle_A |01\rangle_B + a_A b_B c_2 |01\rangle_{12} |00\rangle_A |10\rangle_B \\
& + a_A b_B c_2 |11\rangle_{12} |00\rangle_A |10\rangle_B + b_A a_B c_3 |00\rangle_{12} |11\rangle_A |01\rangle_B \\
& - b_A a_B c_3 |10\rangle_{12} |11\rangle_A |01\rangle_B + b_A b_B c_4 |01\rangle_{12} |11\rangle_A |10\rangle_B \\
& - b_A b_B c_4 |11\rangle_{12} |11\rangle_A |10\rangle_B)
\end{aligned} \tag{5}
$$

The measurement operator M is

$$
\begin{aligned}
M = & c(|000000\rangle\langle 000000| + |000001\rangle\langle 000001| \\
& + |000010\rangle\langle 000010| + |000100\rangle\langle 000100| \\
& + \cdots + |001111\rangle\langle 001111| \\
& + \cdots + |011111\rangle\langle 011111|)
\end{aligned} \tag{6}
$$

c is a normalization constant.

After measurement, we got

$$
\begin{aligned}
M|\Phi\rangle = & a_A a_B c_1 |00\rangle |00\rangle |01\rangle + \\
& a_A b_B c_2 |01\rangle |00\rangle |10\rangle + b_A a_B c_3 |00\rangle |11\rangle |00\rangle \\
& + b_A b_B c_4 |01\rangle |11\rangle |10\rangle
\end{aligned} \tag{7}
$$

To realize the transmission, we require two unitary operators. One is U which is expressed by a $2^6 \times 2^6$ matrix.

$$
\begin{aligned}
U_{1,2} &= 1 \quad U_{2,1} = 1 \quad U_{1,1} = 0 \quad U_{2,2} = 0 \\
U_{3,19} &= 1 \quad U_{19,3} = 1 \quad U_{3,3} = 0 \quad U_{19,19} = 0 \\
U_{5,14} &= 1 \quad U_{14,5} = 1 \quad U_{5,5} = 0 \quad U_{14,14} = 0 \\
U_{7,31} &= 1 \quad U_{31,7} = 1 \quad U_{7,7} = 0 \quad U_{31,31} = 0 \\
others\ U_{i,i} &= 1 \quad and \quad U_{i,j} = 0 \quad i \neq j
\end{aligned}
$$

then the state is

$$
\begin{aligned}
|\Psi\rangle = & m_1 c_1 |00\rangle |00\rangle |00\rangle + m_2 c_2 |00\rangle |00\rangle |10\rangle \\
& + m_3 c_3 |00\rangle |01\rangle |00\rangle + m_4 c_4 |00\rangle |01\rangle |10\rangle
\end{aligned} \tag{8}
$$

where $m_1 = a_A a_B$, $m_2 = a_A b_B$, $m_3 = b_A a_B$, $m_4 = b_A b_B$ and we perform the second operator F that is also a $2^6 \times 2^6$ matrix.

$$
\begin{aligned}
F_{3,3} &= \frac{m_1}{m_2} \quad F_{5,5} = \frac{m_1}{m_3} \quad F_{7,7} = \frac{m_1}{m_4} \\
F_{8,8} &= 0 \quad F_{9,9} = 0 \\
F_{10,10} &= 0 \quad F_{11,11} = 0 \\
F_{3,9} &= \sqrt{1 - \left|\frac{m_1}{m_2}\right|^2} \quad F_{8,3} = -\sqrt{1 - \left|\frac{m_1}{m_2}\right|^2} \\
F_{8,9} &= \left(\frac{m_1}{m_2}\right)^* \\
F_{5,10} &= \sqrt{1 - \left|\frac{m_1}{m_3}\right|^2} \quad F_{9,5} = -\sqrt{1 - \left|\frac{m_1}{m_3}\right|^2} \\
F_{9,10} &= \left(\frac{m_1}{m_3}\right)^* \\
F_{7,11} &= \sqrt{1 - \left|\frac{m_1}{m_4}\right|^2} \quad F_{10,7} = -\sqrt{1 - \left|\frac{m_1}{m_4}\right|^2} \\
F_{10,11} &= \left(\frac{m_1}{m_4}\right)^* \quad F_{11,8} = 1 \\
other\ F_{i,i} &= 1, \ F_{i,j} = 0
\end{aligned}
$$

here we suppose m_1 is the least. We get the state

$$
\begin{aligned}
|\Psi'\rangle = & m_1(c_1 |00\rangle |00\rangle |00\rangle + c_2 |00\rangle |00\rangle |10\rangle + \\
& c_3 |00\rangle |01\rangle |00\rangle + c_4 |00\rangle |01\rangle |10\rangle)
\end{aligned} \tag{9}
$$

we perform the projective measurement given as

$$
P_s = |00\rangle_{12} |0\rangle_{A_1} |0\rangle_{B_2 B_2} \langle 0|_{A_1} \langle 0|_{12} \langle 00| \tag{10}
$$

if we get 1, it shows the success of us. The probability is easily got as $4|m_1|^2$ which is equal to $4\left|\sin(\frac{\pi}{4} + \triangle_A)\sin(\frac{\pi}{4} + \triangle_B)\right|^2$. For more distinctly to observe, we propose the FIG.1 to exhibit the relation between the probability and $\triangle_A, \triangle_B$.

III. TRANSMIT QUANTUM STATES OF MULTIPARTITE PARTICLES BY MULTIPARTITE ANALOGOUS BELL STATES

In this section, we try to apply our scheme to the multipartite particles system. So we take the transfer of three particles quantum states by three analogous Bell states as the example. We have three pairs of entanglement paticles whose states are

$$
|\phi\rangle_A = a_A |00\rangle_A + b_A |11\rangle_A \tag{11}
$$

$$
|\phi\rangle_B = a_B |01\rangle_B + b_B |10\rangle_B \tag{12}
$$

$$
|\phi\rangle_C = a_C |00\rangle_C - b_C |11\rangle_C \tag{13}
$$

The state of the syetem of three particles is

$$
\begin{aligned}
\left|\phi\right\rangle_{123} &= c_1\left|000\right\rangle_{123} + c_2\left|001\right\rangle_{123} + c_3\left|010\right\rangle_{123} \\
&\quad + c_4\left|011\right\rangle_{123} + c_5\left|100\right\rangle_{123} + c_6\left|101\right\rangle_{123} \\
&\quad + c_7\left|110\right\rangle_{123} + c_8\left|111\right\rangle_{123}
\end{aligned} \tag{14}
$$

Therefor, we gain the whole state which is

$$
\begin{aligned}
\left|\Phi\right\rangle &= \left|\phi\right\rangle_{123}\left|\phi\right\rangle_A\left|\phi\right\rangle_B\left|\phi\right\rangle_C \\
&= c_1 a_A a_B a_C\left|000\right\rangle_{123}\left|00\right\rangle_A\ \left|01\right\rangle_B\left|00\right\rangle_C + \cdots - \\
&\quad c_2 a_A a_B b_C\left|001\right\rangle_{123}\left|00\right\rangle_A\ \left|01\right\rangle_B\left|11\right\rangle_C + \cdots + \\
&\quad c_3 a_A b_B b_C\left|010\right\rangle_{123}\left|00\right\rangle_A\ \left|10\right\rangle_B\left|00\right\rangle_C + \cdots - \\
&\quad c_4 a_A b_B b_C\left|011\right\rangle_{123}\left|00\right\rangle_A\ \left|10\right\rangle_B\left|11\right\rangle_C + \cdots + \\
&\quad c_5 b_A a_B a_C\left|100\right\rangle_{123}\left|11\right\rangle_A\ \left|01\right\rangle_B\left|00\right\rangle_C + \cdots - \\
&\quad c_6 b_A a_B b_C\left|101\right\rangle_{123}\left|11\right\rangle_A\ \left|01\right\rangle_B\left|11\right\rangle_C + \cdots + \\
&\quad c_7 b_A b_B a_C\left|110\right\rangle_{123}\left|11\right\rangle_A\ \left|10\right\rangle_B\left|00\right\rangle_C + \cdots - \\
&\quad c_8 b_A b_B b_C\left|111\right\rangle_{123}\left|11\right\rangle_A\ \left|10\right\rangle_B\left|11\right\rangle_C + \cdots
\end{aligned} \tag{15}
$$

To prepare the state to the expected state, we propose a unitary operator U which is a $2^9 \times 2^9$ matrix. The elements of U are

$$
\begin{aligned}
U_{7,72} &= 1 \quad U_{72,7} = 1 \quad U_{7,7} = 0 \quad U_{72,72} = 0 \\
U_{13,137} &= 1 \quad U_{137,13} = 1 \quad U_{13,13} = 0 \quad U_{137,137} = 0 \\
U_{15,204} &= 1 \quad U_{204,15} = 1 \quad U_{15,15} = 0 \quad U_{204,204} = 0 \\
U_{37,307} &= 1 \quad U_{307,37} = 1 \quad U_{37,37} = 0 \quad U_{307,307} = 0 \\
U_{39,366} &= 1 \quad U_{366,39} = 1 \quad U_{39,39} = 0 \quad U_{366,366} = 0 \\
U_{45,441} &= 1 \quad U_{441,45} = 1 \quad U_{45,45} = 0 \quad U_{441,441} = 0 \\
U_{47,508} &= 1 \quad U_{508,47} = 1 \quad U_{47,47} = 0 \quad U_{508,508} = 0 \\
others\ U_{i,i} &= 1 \quad and \quad U_{i,j} = 0 \quad i \neq j
\end{aligned}
$$

Then, we find that the coefficients of the terms are different. This will lead to the condition that we could not get the ideal results. To deal with it, we propose the second unitary which is F. It is also a $2^9 \times 2^9$ matrix. And the elements are

$$
\begin{aligned}
F_{7,7} &= \frac{m_1}{m_2} \quad F_{13,13} = \frac{m_1}{m_3} \quad F_{17,17} = \frac{m_1}{m_4} \\
F_{37,37} &= \frac{m_1}{m_5} \quad F_{39,39} = \frac{m_1}{m_6} \quad F_{45,45} = \frac{m_1}{m_7} \\
F_{47,47} &= \frac{m_1}{m_8} \\
F_{7,65} &= \sqrt{1-\left|\frac{m_1}{m_2}\right|^2} \qquad F_{64,7} = -\sqrt{1-\left|\frac{m_1}{m_2}\right|^2} \\
F_{64,65} &= \left(\frac{m_1}{m_2}\right)^* \\
F_{13,66} &= \sqrt{1-\left|\frac{m_1}{m_3}\right|^2} \qquad F_{65,13} = -\sqrt{1-\left|\frac{m_1}{m_3}\right|^2} \\
F_{65,66} &= \left(\frac{m_1}{m_3}\right)^* \\
F_{15,67} &= \sqrt{1-\left|\frac{m_1}{m_4}\right|^2} \qquad F_{66,15} = -\sqrt{1-\left|\frac{m_1}{m_4}\right|^2} \\
F_{66,67} &= \left(\frac{m_1}{m_4}\right)^* \\
F_{37,68} &= \sqrt{1-\left|\frac{m_1}{m_5}\right|^2} \qquad F_{67,37} = -\sqrt{1-\left|\frac{m_1}{m_5}\right|^2} \\
F_{67,68} &= \left(\frac{m_1}{m_5}\right)^* \\
F_{39,69} &= \sqrt{1-\left|\frac{m_1}{m_6}\right|^2} \qquad F_{68,39} = -\sqrt{1-\left|\frac{m_1}{m_6}\right|^2} \\
F_{68,69} &= \left(\frac{m_1}{m_6}\right)^* \\
F_{45,70} &= \sqrt{1-\left|\frac{m_1}{m_7}\right|^2} \qquad F_{69,45} = -\sqrt{1-\left|\frac{m_1}{m_7}\right|^2} \\
F_{69,70} &= \left(\frac{m_1}{m_7}\right)^* \\
F_{47,71} &= \sqrt{1-\left|\frac{m_1}{m_8}\right|^2} \qquad F_{70,47} = -\sqrt{1-\left|\frac{m_1}{m_8}\right|^2} \\
F_{70,71} &= \left(\frac{m_1}{m_8}\right)^* \\
F_{64,64} &= F_{65,65} = F_{66,66} = F_{67,67} = F_{68,68} = F_{69,69} \\
&= F_{70,70} = F_{71,71} = 0 \\
F_{71,64} &= 1 \qquad other\ F_{i,i} = 1,\ F_{i,j} = 0
\end{aligned}
$$

where $m_1 = a_A a_B a_C$, $m_2 = a_A a_B b_C$, $m_3 = a_A b_B b_C$, $m_4 = a_A b_B b_C$, $m_5 = b_A a_B a_C$, $m_6 = b_A a_B b_C$, $m_7 = b_A b_B a_C$, $m_8 = b_A b_B b_C$. And we suppose the $|m_1|$ is the least of all the coefficients of F.

After measurement, the state is

$$
\begin{aligned}
|\Psi\rangle \; = \; & m_1(c_1 |000\rangle_{123} |00\rangle_A \; |01\rangle_B |00\rangle_C + \\
& c_2 |000\rangle_{123} |00\rangle_A \; |01\rangle_B |10\rangle_C + \\
& c_3 |000\rangle_{123} |00\rangle_A \; |11\rangle_B |00\rangle_C + \\
& c_4 |000\rangle_{123} |00\rangle_A \; |11\rangle_B |10\rangle_C + \\
& c_5 |000\rangle_{123} |10\rangle_A \; |01\rangle_B |00\rangle_C + \\
& c_6 |000\rangle_{123} |10\rangle_A \; |01\rangle_B |10\rangle_C + \\
& c_7 |000\rangle_{123} |10\rangle_A \; |11\rangle_B |00\rangle_C + \\
& c_8 |000\rangle_{123} |10\rangle_A \; |11\rangle_B |10\rangle_C) + \\
& other \; terms \qquad (16)
\end{aligned}
$$

Observing the state, it is easy to find that we could gain the quantum state of transfer by projective measurement P_s which is

$$P_s = |000\rangle_{123} |0\rangle_{A_2} |1\rangle_{B_2} |0\rangle_{C_2C_2} \langle 0|_{B_2} \langle 1|_{A_2} \langle 0|_{123} \langle 000| \qquad (17)$$

Therefor, we apply the scheme of transfer quantum states of multipartite particles by multipartite analogous Bell states successfully.

IV. CONCLUSION

It shows that we could be successful to complete the transfer of bipartite quantum states and quantum states of multipartite particles by the analogous Bell states, and the unitary operators are effective to overcome the difficulties that are produced by the departures. From Fig.1 and Fig.2, we could distinctly know the relation between the probability transmission and the departures, For example, when the departures are equal to 0 that it means the channels are the Bell states, the probability is 1. Therefor we achieve our tasks successfully.

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But for the difficulty of exactly controling the process, it is nearly no possibility to prepare the perfect Bell states. It is easy to produce some departures from Bell states. It is to say

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$$\begin{aligned}
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a_A &= \sin(\frac{\pi}{4} + \triangle_A) \quad b_A = \cos(\frac{\pi}{4} + \triangle_A)\\
|\phi\rangle_B &= a_B\,|01\rangle_B + b_B\,|10\rangle_B \qquad |a_B|^2 + |b_B|^2 = 1 \quad (2)\\
a_B &= \sin(\frac{\pi}{4} + \triangle_B) \quad b_B = \cos(\frac{\pi}{4} + \triangle_B).
\end{aligned}$$

We show how to transmit an arbitrary bipartite state by two analogous Bell states

$$|\phi\rangle_{12} = c_1\,|00\rangle_{12} + c_2\,|01\rangle_{12} + c_3\,|10\rangle_{12} + c_4\,|11\rangle_{12} \quad (3)$$

The whole state is

$$\begin{aligned}
|\Phi\rangle &= a_A a_B c_1\,|00\rangle_{12}\,|00\rangle_A\,|01\rangle_B + a_A b_B c_2\,|01\rangle_{12}\,|00\rangle_A\,|10\rangle_B\\
&\quad + b_A a_B c_3\,|10\rangle_{12}\,|11\rangle_A\,|01\rangle_B + b_A b_B c_4\,|11\rangle_{12}\,|11\rangle_A\,|10\rangle_B\,.
\end{aligned} \quad (4)$$

Then by carrying out Bell-operation on the first parti-